Food, Energy, and the Environment:

Nancy R. Sorrells
David Pimentel

DAILY WE READ of the growing concern over rising population numbers, increasing environmental pollution, decreasing supplies of energy resources, and countless other discouraging trends. The world population is currently 4.3 billion (10^9), and it is expected to increase to over 6 billion by the end of the century (National Academy of Sciences 1977). Our population is already straining available natural resources as we attempt to provide adequate food, shelter, and other essentials for everyone.

Before we can begin to solve these supply/demand problems, we must understand the interdependencies of food, land, and energy resources. Each of these resources is related to all the others, and how we use one affects how we can use the others. Figure 1 illustrates the complexity of our ecosystem and indicates why the entire system must be understood before we can effectively improve our use of these resources.

Fossil Energy and Food Production

Fossil energy is one of the resources that affects the use of numerous other resources in meeting the needs of society, for example, for food. The use of energy in agriculture has increased faster than energy use in any other sector of our economy. This trend is especially evident in industrialized nations. Large quantities of fuel are used in making fertilizers, pesticides, and farm machinery. Additional fuel is then used to operate the machinery.

In addition to requiring huge investments of fossil fuel, energy-intensive agricultural practices add to environmental pollution and contribute to serious degradation of land and water resources. Soil erosion has already caused significant losses of crop land and reductions in agricultural productivity in the United States and other countries throughout the world (Eckholm 1976; Pimentel, *et al.* 1976).

Human societies can no longer afford to waste energy and degrade land and water resources in order to produce food. We must modify our present practices and develop alternative agricultural methods to meet the increasingly critical need for food. In this article, we outline current energy, land, and water resource use in the food production systems of industrial societies and then analyze alternative technologies that have the potential for an ecologically sound food system that requires reduced energy inputs.

Seventeen percent of all the fossil energy used in the United States goes into producing food (Pimentel and Pimentel 1979). Growing the food (agricultural production) uses about 6%; the remaining 11% is used to process, package, transport, store, and prepare food in the home.

Most of the energy used in agricultural production goes into either manufacturing fertilizers and pesticides or running farm machinery. Fertilizers and pesticides are made directly from fossil energy. Nitrogen fertilizers are made primarily from natural gas; pesticides are made from petroleum.

The amount of energy necesary to produce food crops varies greatly. Culturing fruits, vegetables, and grains generally requires from 0.5 to 5 calories of energy input per 1 food calorie produced. In general, grain takes the least energy to produce; vegetables and fruits require more.

However, the production of animal protein requires the greatest investment of energy. From 10 to 90 kcal of fossil energy are required to produce 1 kcal of animal protein (Pimentel 1980). Before the animals themselves can be slaughtered for food, forage and grain crops to feed them must be grown and harvested. This intermediate step is what makes animal protein so energy expensive. Most of the grains fed to animals are also suitable human food. In

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Nancy R. Sorrells is a research aide in the department of entomology, Cornell University, Ithaca, New York 14853. She received her B.S. degree from Cornell and has taught biology at Valley Central School, Montgomery, New York. David Pimentel is professor of insect ecology and agricultural sciences in the College of Agriculture and Life Sciences, Cornell University, Ithaca, New York 14853. He received a B.S. degree from the University of Massachusetts and a Ph.D. degree from Cornell. He currently serves on the Commission on International Relations, National Academy of Sciences, the Energy Research Advisory Board of the Department of Energy, the Research Advisory Committee of the Agency for International Development, the AAAS Climate Committee, and is chairman of the Environmental Studies Board of the National Academy of Sciences. He has published numerous articles and has lectured extensively throughout the world.

Alternatives for Creating New Lifestyles

industrialized countries, 90% of the grain harvested is cycled through livestock to produce meat, eggs, and milk.

Production of plant protein is approximately 20 times more efficient than animal protein production. Twenty times more protein is produced in raising soybeans rather than raising hogs to produce pork, but the energy investment required is the same.

Once food is produced, it is processed and packaged to protect it from deterioration and facilitate its wide distribution in the marketplace. Processing makes perishable foods such as fruits and vegetables available year round. Canning, freezing, drying, salting, freeze-drying, and smoking are all processes used to preserve foods.

In industrialized nations, large amounts of fossil energy are used to preserve, process, and package foods. Growing sweet corn on the farm represents only 10% of the total energy required to produce, process, market, and cook a 1 kg can of sweet corn (fig. 2). Most of the

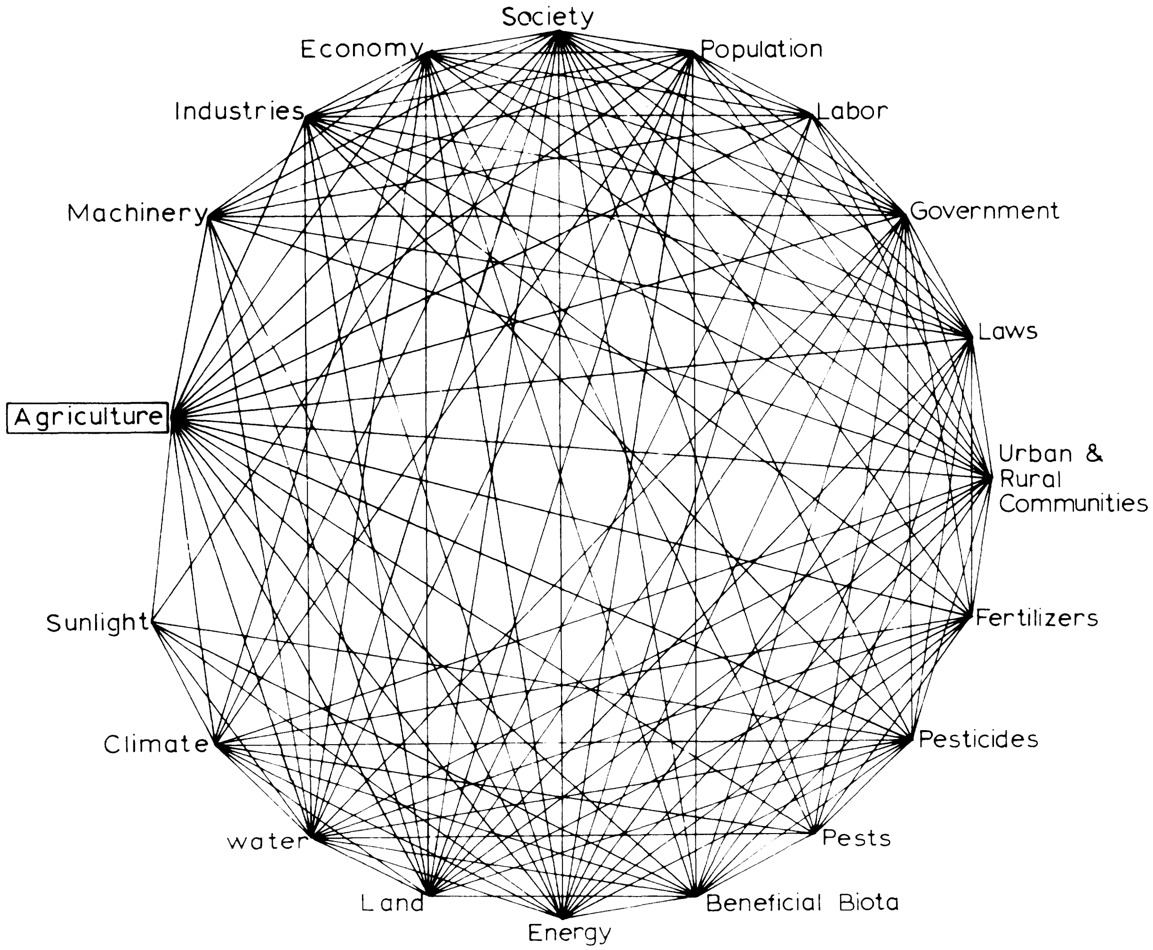

FIGURE 1. The interdependency of agriculture and the ecological and social system.

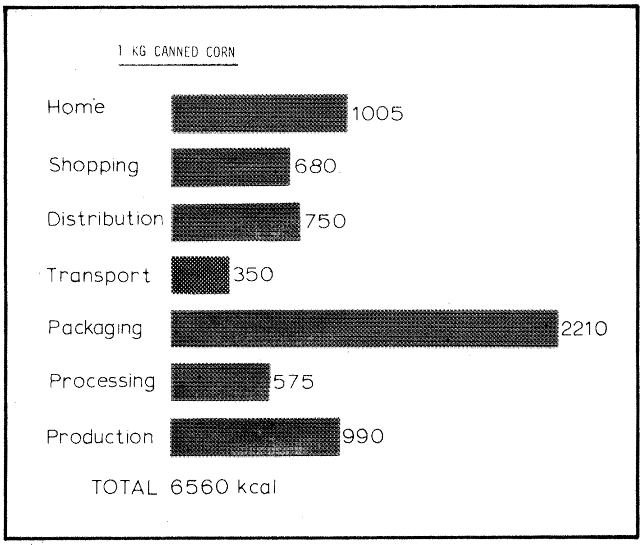

FIGURE 2. Energy inputs for a 1 kg can of sweet corn. (Note, distribution includes storage and home includes refrigeration, cooking, preparation, and washing. One kilogram of corn contains 825 kcal of food energy.)

nearly 2,800 kcal expended in processing goes into the manufacturing of the steel can. Canning the corn requires approximately 600 kcal, but producing the steel packaging requires about 2,200 kcal.

The energy required for freezing food is even greater than that required for canning. Our 1 kg of sweet corn would require about 1,800 kcal/kg for processing if it were frozen. Canning requires only heating and packaging; freezing may require brief heating (blanching), cooling, packaging, and freezing at -18°C or lower temperatures. After food is frozen, it must be kept at temperatures of -18°C or less. This additional energy cost makes the total energy input for frozen food substantially greater than that for canned food. Fortunately, the moisture-resistant plastic and paper containers used for frozen foods require less energy to manufacture than the metal cans or glass jars used for canned food. An important consideration is that the overall nutritive value and palatability of frozen foods, especially vegetables, are superior to canned foods.

Moving food from the farm to the home is another part of the food system. More than half our food (60%) is transported by truck; the remainder by rail. The energy input per kilogram of food transported averages 350 kcal. Frequently, more energy is required to move food to the marketplace. Just to transport a head of lettuce by truck from California to New York requires 1,800 kcal. The head of lettuce has an energy value of 50 kcal; thus about 36 kcal of energy are expended per kcal of food energy in the lettuce for transportation alone.

Even more energy is used each spring when strawberries from California are flown to New York. The energy used to transport 1 kg of strawberries, which has 354 kcal of food energy, is 30,700 kcal. Thus approximately 87 kcal of fossil energy is spent per kcal of strawberries just to provide a distant New Yorker with fresh strawberries.

After food is finally brought home, it still must be prepared; and this, too, takes energy. In industrialized nations, an estimated 9,000 kcal of fossil energy are used per person per day just for home refrigeration and cooking foods using gas or electricity. Cooking with gas—which is more efficient than cooking over an open fire or with electricity—is only 33% efficient in transferring energy to food. Thus, both the kind of fuel available and the equipment used influences the amount of energy needed to process a given amount of food.

Energy-intensive Agriculture and Environmental Pollution

The industrialized agricultural production system, in addition to consuming large amounts of fossil energy, also causes serious environmental problems. Vast areas of land are used for crops and pastures, and much of this land is exposed to agricultural chemicals including pesticides and fertilizers. Though these chemicals help increase crop yields, they also find their way into the environment where they cause problems.

Each year in the United States, pesticides cause a minimum of $1 billion damage to the environment and public health (Pimentel, *et al.* 1979). Concern has been expressed about the 45,000 Americans—200 of whom die—who are poisoned each year with pesticides. Other major problems posed by pesticides include: livestock poisoning; increased pest control expenses resulting from the destruction of natural enemies and pesticide resistance; crop pollination problems resulting from honeybee losses; crop losses; fish and wildlife destruction; and various governmental expenditures for reducing environmental and social costs resulting from widespread pesticide use (Pimentel, *et al.* 1979).

Nitrogen added in large quantities to agricultural crop land often leaches into ground water and contaminates it. Drinking water can be contaminated by nitrates and nitrites; at high enough levels, these can be hazardous to humans, especially young children. Additional nitrogen in lakes and streams can increase eutrophication and cause further environmental problems.

In addition to hazards posed by agricultural chemicals, soils eroded from agricultural land in the United States adversely affect the environment and contribute to loss of productivity. To offset this loss of topsoil and maintain productivity, more fertilizer is needed to maintain yields.

The extent of soil erosion is directly related to rapid water runoff from agricultural lands. Water runs off carrying with it soil, fertilizers, and pesticides. This water is not available for crop production and lack of water reduces yields. In addition, crops in low-lying areas are sometimes flooded. It is estimated that American farmers lose several million dollars in crops annually because of water runoff and flooding (United States Department of Agriculture 1965).

Developing Alternatives

In developing an alternative system of agriculture, the major focus should be on production. This aspect of the food system uses the largest quantity of land, water, and energy resources and engenders more severe environmental problems than food processing, packaging, transporting, or cooking. A highly productive system for the future should conserve land, water, and energy resources while minimizing the impact of food production on the natural biota and human health.

Unfortunately, current agricultural management practices do not conserve land, water, and energy resources. As population continues to increase, crop land is being removed from production and used for housing, industry, and other human activities. Over the last thirty years, an area equivalent to the state of Nebraska has been blacktopped to provide highways. To compensate for the loss of land, greater energy inputs have been required to maintain high levels of food and fiber production from the agricultural land remaining. Because energy supplies are finite, we urgently need to formulate and implement sound land use policies in the United States that will protect and preserve land for agricultural production.

Within limits, energy can also be substituted for water resources. Irrigation can make arid land suitable for crops. Energy is also often used to replace labor with machinery. As long as fuel is abundant, these trade-offs can continue to be effective.

Crop rotation and strip-cropping are two inexpensive strategies that effectively reduce soil erosion and water runoff. Planting a cover crop after harvesting a cash crop in the fall is another good technique for slowing soil erosion.

In some areas, no-till or minimum tillage techniques can also reduce soil erosion. No tillage or minimum tillage refers to planting a crop entirely without tillage or with just enough tillage to allow the seed to germinate and emerge. In one experiment, erosion from corn grown with no-tillage was 1/100th that of conventionally grown corn. However, some costs can be associated with this technique. Because of increased pest problems, two to four times more pesticides are used in no-till cropping than in normal cropping systems. Therefore, because of the large energy inputs represented by pesticides, no-till technology uses as much energy as conventional tillage even though less fuel is used for plowing with the tractor.

In hilly areas, terracing has been effective in protecting valuable topsoil. An initial investment is required to construct the terraces; but once in place, they are permanent and easy to maintain.

The techniques used to conserve and protect topsoil also reduce the rate of water runoff and conserve water for higher crop yields.

Practical alternative technologies also exist that could be more widely used to reduce energy requirements and maintain current crop yields. For example, the labor input for most crops produced using intensive mechanization is relatively small; some tasks could be conducted with a small increase in labor that would significantly increase energy efficiency. Applying herbicide to a hectare of land using a hand-sprayer requires about 900 kcal of energy; the same task carried out with a 50 horsepower tractor requires 52,000 kcal (Pimentel and Pimentel 1979).

Because one of the largest energy investments in crop production is making farm machinery and fueling it, this segment needs special consideration. One viable alternative would be to use machinery more precisely scaled to its job and then to operate it at the most efficient speeds. Smaller tractors and more acres tended per tractor would increase efficiency.

For most crops, the single largest energy input is for fertilizer. At present, livestock manure is seldom used effectively even though 90% of livestock manure is applied to agricultural land (Pimentel, *et al.* 1973). Usually, manure is spread directly on crop land from livestock confinement areas and leached away during the winter months. An alternative is to hold manure in small ponds or holding tanks and spread it in spring when the crops could immediately use the nutrients.

The need for nitrogen fertilizer can also be reduced by planting legumes or other crops. For instance, if rotation is not feasible, legumes can be planted between corn rows in August and plowed under in the early spring.

The expansion of plant breeding programs holds much promise for reducing energy inputs in crop production. Breeding crops for resistance to insects and diseases would reduce the need for pesticides.

Another way to conserve energy in agriculture is to grow plants and animals that require the least investment in fuel to supply the most nutritious food. Though this technique may not always be practical, much can be learned by determining the amount of energy required to produce different crops and livestock with different nutrients. Most plant proteins are significantly less expensive in relation to the energy required to produce them than animal proteins. Significant variations also exist between livestock types in the energy efficiencies or producing animal protein products. Milk and broilers require from one-half to one-fifth less energy than is required to produce an equivalent amount of protein in beef.

Many nutrients other than calories are essential for human health. Vitamin C is an essential nutrient found in both oranges and fresh tomatoes. Though oranges have approximately twice as much Vitamin C per unit weight as tomatoes, 1 million kcal are required to produce a metric ton of oranges; only 0.3 million kcal are required to produce a metric ton of tomatoes. Thus nearly twice as much Vitamin C can be produced growing tomatoes using the same energy required to produce an equivalent amount of oranges. In addition, tomatoes can be grown in both tropical and temperate zones.

Food processing techniques used in the future will have to be evaluated on the basis of energy efficiency and nutrient availability rather than on the basis of convenience or palatability. Substantial energy savings are possible if we modify our food packaging practices. One might seriously question the efficiency of placing two crackers in a plastic pouch that requires more energy to produce than its contents. And one can seriously question the need to invest energy in producing the 1 kcal soft drink that is then packaged in an aluminum can that took 1,600 kcal to produce and another 600 kcal to process. Reduced energy inputs in packaging and improved environmental quality would result if we used glass or metal containers rather than throwaways. Of course, some costs and inconveniences are associated with collecting, rinsing, and returning containers, but the energy and environmental benefits are significant.

Diets typical of industrialized nations are both high in calories and protein, especially animal protein. Changing eating patterns to emphasize the consumption of less meat and animal products would significantly reduce the land and energy inputs required in the food systems of industrialized nations.

The average American consumes 102 g of protein per day, 70 g of which are animal protein. Contrast this figure with the Food and Agriculture Organization (1973) recommendation that 41 g per day is an adequate protein intake to maintain health. If the United States were to move from a grain- and grass-fed livestock system to only a grass-fed system, energy requirements could be reduced by about 60%; however, the total amount of protein that could be produced would be reduced by about 50%. Thus *per capita* consumption of protein in the United States would decline to 70 g per day per person; this amount is still considerably above the 41 g level recommended by FAO.

Significant reductions in energy use as well as land and water resource use are possible by modifying the diets and eating patterns of Americans. Further reductions in the quantity of energy and other resources expended are possible if the total calorie intake of the population were decreased from the present 3,300 kcal to the desirable, but still healthy, level of less than 2,500 kcal.

Recommendations

Our estimate is that at least 50% of the fossil energy used in the current food production system could be saved while maintaining crop yields and improving environmental quality.

To accomplish this goal, we would need to make the following modifications or changes to the present system:

- Reduce animal protein consumption by one-half and increase quantities of grains, legumes, and other vegetables consumed by the population.
- Improve home cooking and food preparation techniques.
- Decrease the number of individually packaged foods; encourage the use of recyclable containers.
- When nutrient retention is adequate, favor canning and other energy-efficient food processing techniques over freezing for preserving and processing food.
- Select livestock and crops based on nutrient content and energy efficiency of production.
- Whenever possible, locate food production facilities close to consumer markets.
- Use farm machinery appropriate to the task and acreage cultivated.
- Increase the use of livestock and green manures.
- Employ nonchemical biological and cultural pest controls instead of pesticides where possible.
- Control soil erosion and water runoff by using crop rotation, contour planting, terracing, cover crops, and leaving crop remains on the surface of the land.
- Initiate land use policies that will ensure sufficient land remains for cultivation to meet the future needs of the nation.
- Increase crop production in areas that receive sufficient natural rainfall; when irrigation is necessary, use water and energy wisely.

Clearly, there are many ways through which industrial nations can reduce the energy required to produce food. Along with energy savings would come extra dividends in the form of improved diets and better environmental quality. Sufficient food is being produced in the world today to feed its population if it were effectively distributed. If we were to make the changes described, agricultural production would be not only ecologically and energetically sound, but also would be sustainable and capable of meeting the food needs of the world population.

With land, water, and energy resources already in short supply in many parts of the world, it may not be possible to feed the world population adequately in the future. We recognize that as we develop ecologically and energetically sound food production practices, we must also control population. Clearly, if humans do not choose to control their numbers, nature will.

References

ECKHOLM, E.P. 1976. *Losing ground.* New York: Norton.

FOOD AND AGRICULTURE ORGANIZATION (FAO). 1973. *Energy and protein requirements.* (Report of a Joint FAO/WHO *Ad Hoc* Expert Committee, FAO Nutrition Meeting Report Series No. 52.) Rome: Food and Agriculture Organization.

NATIONAL ACADEMY OF SCIENCES. 1977. *Supporting papers: World food and nutrition study.* Washington, D.C.: National Academy of Sciences.

PIMENTEL, D. (ed.) (In press). *Handbook of energy utilization in agriculture.* Boca Raton, Florida: CRC Press.

______, HURD, L.E., BELLOTTI, A.C., FORSTER, M.J., OKA, I.N., SHOLES, O.D., and WHITMAN, R.J. 1973. Food production and the energy crisis. *Science* 182:443.

______, TERHUNE, E.C., DYSON-HUDSON, R., ROCHEREAU, S., SAMIS, R., SMITH, E., DENMAN, D., REIGSCHNEIDER, D., and SHEPARD, M. 1976. Land degradation: Effects on food and energy resources. *Science* 194:149.

______, and PIMENTEL, M. 1979. *Food, energy, and society.* London: Edward Arnold (Publishers) Ltd.

______, ANDOW, D., GALLAHAN, D., SCHREINER, I., THOMPSON, T., DYSON-HUDSON, R., JACOBSON, S., IRISH, M., KROOP, S., MOSS, A., SHEPARD, M., and VINZANT, B. 1979. Pesticides: Environmental and social costs. *In* Pimentel, D., and Perkins, J.H., (eds.). *Pest control: Cultural and environmental aspects.* Boulder, Colorado: Westview Press.

UNITED STATES DEPARTMENT OF AGRICULTURE. 1965. *Losses in agriculture.* (Agricultural Research Service Handbook No. 291.) Washington, D.C.: U.S. Department of Agriculture.

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students and will continue to be modified to meet the changing needs of future students at UW-S. For example, during the 1979-80 academic year, this biology course is being used in the Extended Degree Program at UW-S. This is the first lab course offered to off-campus students at UW-S. Each extended degree student is given one year to complete all of the modules and has minimal face-to-face contact with the instructor. To date, only one student has completed the course in this manner. I am anxiously awaiting additional student reactions to this phase of the course's development.

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References

BARMAN, C. R. 1979. *Introductory biology: A self-paced comtency-based course.* Superior: University of Wisconsin-Superior.

KULIK, J.A., KULIK, C.L.C., and SMITH, B.B. 1976. Research in the personalized system of instruction. *Programmed Learning and Educational Technology* 13:23.

PASCARELLA, E. T. 1977. Student motivation as a differential predictor of course outcomes in personalized system of instruction and conventional methods. *The Journal of Educational Research* 71:21.

RUSKIN, R. S. 1977a. The personalized system of instruction (PSI). *Educational Technology,* September.

______, and RUSKIN, R. L. 1977b. Personalized instruction and its relation to other instructional systems. *Educational Technology,* September.

TOROP, W. 1978. An analysis of individualized learning system chemistry. *Journal of College Science Teaching* 8(2):114.

WISCONSIN DEPARTMENT OF PUBLIC INSTRUCTION. 1970. *A guide to science curriculum development* (Bulletin No. 161). Madison: Wisconsin Department of Public Instruction.